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A PROCEDURE FOR STANDARDIZATION OF COLOR INFRARED FILM RESPONSE

Richard L. LaPado and Robert E. Ekstrand

Prepared by
ESL INCORPORATED
Sunnyvale, Calif.
for Ames Research Center

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16. Abstract

The increasing use of color infrared film for various remote sensing applications has pointed up several problems inherent with this type of film. These relate to the instability or variability of the relative sensitivities of the three dye layers within the film and the resultant variations in color balance when the film is used.

In order to optimize film response and to achieve more consistent results, a procedure has been developed and utilized for the past 18 months at the Earth Resources Aircraft Project, NASA Ames Research Center.

The procedure establishes a sensitometric aim point with which all new batches of film are compared. Through the use of color compensation filters and change in basic exposure, the new film is exposed to produce imagery with the response characteristics of the aim curves.

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A PROCEDURE FOR STANDARDIZATION OF COLOR INFRARED FILM RESPONSE

1. INTRODUCTION.

Infrared sensitive color films have, for several years, been a primary tool in photographic remote sensing. There have been numerous published documents concerning the physical characteristics and exposure criteria for these films.[1,2] These data, however, are based upon the assumption that these films have a fixed response and that once the proper exposure is determined for a particular scene, repetitive coverage can be obtained and temporal changes monitored by means of color shifts in the resulting image. In reality, the variation in the color balance between rolls of these films is often greater than the variation in reflectance from the ground scene over a given period of time.

A procedure that quantifies these variations in color balance through sensitometric testing and allows for preflight adjustments to exposure and filtration has been used with excellent results for the Earth Resources Aircraft Project, NASA Ames Research Center, since June 1973. This paper describes the technique used to achieve a normalized sensitivity and color balance.

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1. *Kodak Aerial Films and Photographic Plates*, Eastman Kodak Co., 1972.

2. Norman Fritz, "Optimum Methods for Using Infrared Color Films," *Photogrammetric Engineering*, 33 (1967), 1128-38.

2. RESPONSE VARIABILITY.

The increasing use of infrared sensitive color films for various photo interpretation applications has pointed up several problems inherent in this type of film. These problems relate to the instability and variability of the dye layer sensitivities incurred during the manufacturing and ageing processes. The variability of the response characteristics manifests itself in two ways: the first being a differential shift in sensitivity between the three layers and the second being an overall change in film speed due to the summation of shifting responses in all three layers.

The greatest variability is found to exist between emulsion batch numbers and between various width cuts within a batch number, whereas the variation in response between similar width rolls of the same emulsion number are quite small. The effect of storage time on the speed and color balance also turns out to be quite small when the film is stored in a freezer at 0°F and expended within 90 days.

Aside from any inherent film variability, inconsistent film processing is also found to contribute heavily to the varying color balance being imaged on these films. To monitor and control the color balance and speed of this film, processing controls must be established which will assure consistent processing of each roll. Once processing control is established, the color infrared film can be monitored sensitometrically, and changes in relative film speed and color response can be quantified.

3. SENSITOMETRY.

Sensitometry is the science of measuring the photographic behavior of light-sensitive materials under specified processing conditions. The sensitometry for the color infrared films at NASA-Ames is accomplished on an EG&G, Model VI sensitometer. This sensitometer employs a General Electric FT-118 xenon flash tube for the light source. The color temperature of this source is approximately 5900°K and the output power is 5000 meter-candle-seconds at an exposure of 10^{-2} seconds.

Since all three layers in color infrared films are sensitive to blue light, it is necessary to block the blue output of the flash tube. To accomplish this, a Wratten 12 filter is placed between the light source and the film, along with a 2.62 silver-based neutral-density filter (fogged film). The latter filter reduces the overall light output for proper exposure of the control strip. The control strip is actually produced by contact printing a Kodak 21-step calibrated gray scale onto the unexposed film with the sensitometer.

Processing of the control strip is done is accordance with Eastman Kodak's recommended time, temperature, and replenishment rates for normal processing, which uses EA-5 chemistry in the model 1811 Versamat Processor.

4. DENSITOMETRY.

Densitometry is used to quantify the step wedge image created in the sensitometric control process. With color films (including color infrared films), a special densitometer is required

4. -- Continued.

that has provisions for reading diffuse color transmission density.[3] By utilizing an internal filtering system, the densitometer measures the yellow, magenta, and cyan dye layer densities of each of the 21 imaged steps. These values are then plotted as a function of exposure to produce density versus log exposure (H&D) curves for each of the three dye layers (see Figure 1). The resulting graph for each roll of color infrared film contains three curves. The infrared sensitive layer produces cyan dye which provides a measurable density to red, the red sensitive layer produces a magenta dye and a measurable density to green, and the green sensitive layer produces a yellow dye and a measurable density to blue. The position of these curves determines the speed and color balance of the particular emulsion.

5. CALIBRATION PHILOSOPHY.

The fact that color infrared films are sensitive to energy beyond the range of human vision is a primary reason for their utility in remote sensing. At the same time, the inability to visualize the infrared portion of the spectrum precludes the standard color balance that is possible with normal color films. The concept of gray acts as a zero point from which all colors emanate in normal color films. Although the layer sensitivities of color infrared films do not fit the visual gray concept, the

3. American National Standards Institute, Publication PH 2.1-1952.

NASA-AMES RESEARCH CENTER
MOFFETT FIELD, CALIFORNIA

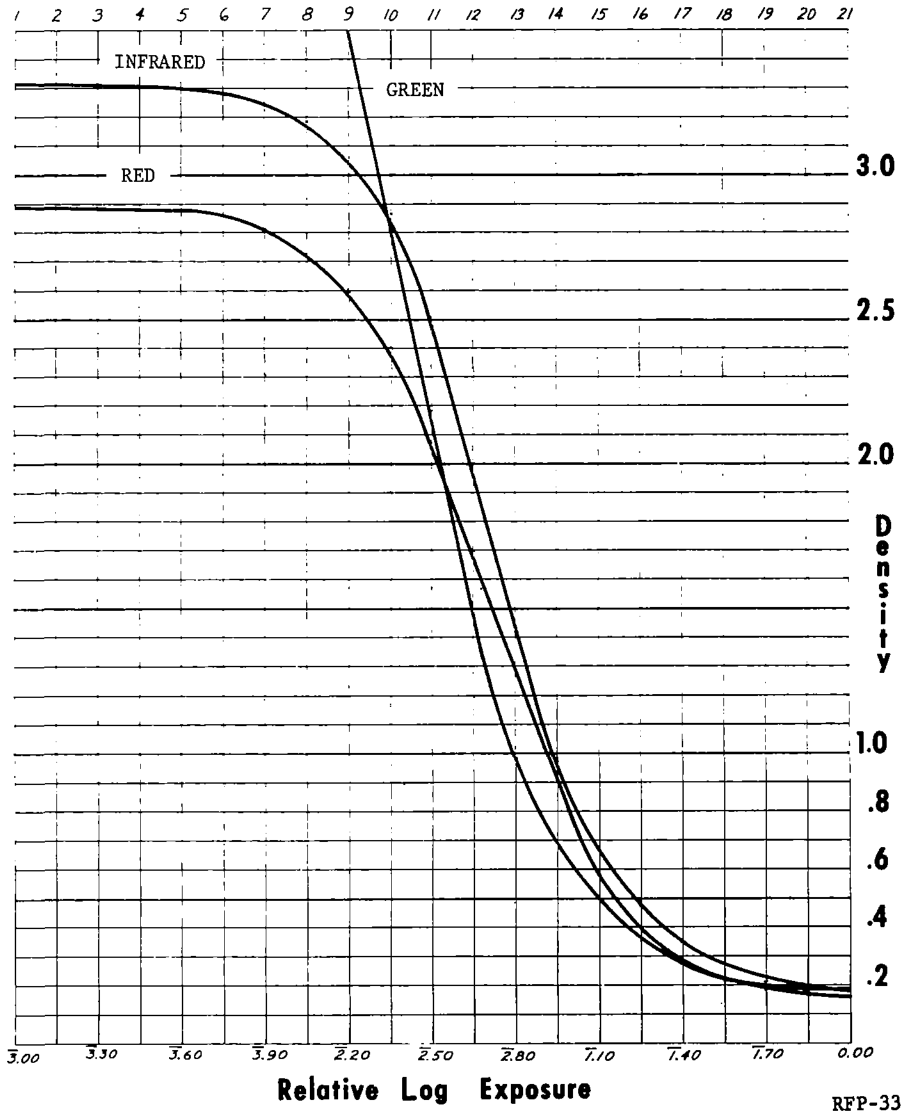
DATE Dec. 14, 1972 BY R. La Pado
MACHINE 1811 TANK ____ TRAY ____
AGITATION ____ REPLENISHMENT ____
FILM 1 2443-105-1 DEVELOPER 1 EA-5

Filtration:
1. Wratten 12
2. 2.62 Ag ND
3. cc 0.40 M
4. cc 0.20 C

	TEMP	TIME	FPM	RE-EXP VOLTS
1	120°F		9.0	
2				
3				
4				
5				
6				

SENSITOMETER NO EG&G TABLET NO. 5372
N.D 2.62 EXPOSURE 10^{-2} SECS.
DENSITOMETER Macbeth APERTURE 3mm

STEP#	1	2	3	4	5	6
B+F						
1	4.81	2.89	3.31			
2	4.81	2.89	3.31			
3	4.78	2.89	3.31			
4	4.75	2.88	3.31			
5	4.67	2.88	3.30			
6	4.51	2.86	3.28			
7	4.33	2.81	3.24			
8	3.96	2.73	3.18			
9	3.50	2.60	3.06			
10	2.88	2.40	2.86			
11	2.18	2.07	2.47			
12	1.54	1.70	1.95			
13	.99	1.30	1.42			
14	.67	.92	.97			
15	.48	.58	.67			
16	.35	.39	.47			
17	.27	.27	.34			
18	.22	.21	.27			
19	.20	.18	.21			
20	.18	.16	.17			
21	.17	.16	.16			



RFP-33

Figure 1. NASA, ARC Color Infrared Standard Aim Curve

primary colors in which the image is rendered are able to produce a neutral gray. The question then arises as to where the gray threshold should fall in the color balance scheme.

The green and red sensitive layers of color infrared films make up two components of a visual gray and correspond to the blue and green layers, respectively, in the normal color reversal films such as SO-397 and 2448. Therefore, it seems logical that the relative sensitivity between the green and red sensitive layers on the color infrared films should be similar to the relative sensitivity between the blue and green sensitive layers on normal color films. This correlation provides for the optimum discrimination in the two visible wavelength layers of the color infrared films and, at the same time, provides a neutral magenta and yellow image balance against which the infrared sensitive cyan layer can be manipulated to modify the threshold of color neutrality.

For this procedure the relative film speed measurements for the color infrared films are based on the speed of the infrared sensitive layer. This is due to the fact that, in order to maintain a specific color balance, it is necessary to be able to adjust the relative speed of each layer independently of the others. It is more practical to change the apparent speed of the IR layer by a change in exposure than by the use of IR absorption filters, whereas the apparent speed of the visible layers can be reduced independently by using color compensating filters.

5.1 Standard Graph.

The color infrared standard is a graph of characteristic curves of the three dye layers that make up Kodak's Aerochrome Infrared film. The position of these curves on the graph determines both the film speed and desired color balance for color infrared films. The standard provides an aim point for the sensitometric calibration of incoming shipments of new color infrared emulsion.

The standard was empirically developed through a series of test flights using a single emulsion of 2443 film type (see Figure 1). Flights were conducted over a variety of ground cover types, varying from desert to heavily forested areas. Following each flight, a sensitometric wedge was exposed on the tail end of the roll. The roll was then processed and the processing control verified by the sensitometric strip. Representative frames of the photography were then selected for densitometric evaluation. The density ranges of the three dye layers were determined, and the appropriate filters selected to shift the average density for each layer to the same density level. The overall exposure was then adjusted to center the average density near 1.0. The flights were repeated using the calculated adjustments to exposure and filtration. The standard graph was then plotted, taking into account all of the filters used to correct the color balance of the film. This graph is now used to achieve the proper exposure and color balance for any color infrared emulsion.

6. CALIBRATION PROCEDURE.

The objective of this procedure is to determine the relative color balance and film speed of emulsion number batches of color infrared film. This determination allows the user to compare the characteristics of a new batch of film to a predetermined standard and make adjustments to the camera exposure and filtration to ensure more consistent image data.

Upon receipt of a new film shipment, a roll from each emulsion number and cut width is selected for testing. Using approximately five feet of film from each roll, two sensitometric wedges are exposed near the center of each strip of film according to the method described in Section 3. Once the wedges have been exposed, they are stored in a manner similar to that of typical operational exposed film prior to processing.

The sensitometric strips are processed at Kodak's recommended time and temperature in EA-5 chemistry, in the same processor as the operational material. After the strips have been processed, a diffuse color transmission densitometer is used to read the density values for the 21 steps on each of the three dye layers. These values are then used to generate graphs of the functional relationship between exposure and density (H&D curves). The result is three separate curves depicting density values as a function of the logarithm of exposure (Log E) for each dye layer.

The relative speed of each roll is determined in the following manner:

1. For each emulsion, determine the density level that represents 0.80 density above the base fog on the infrared sensitive layer.

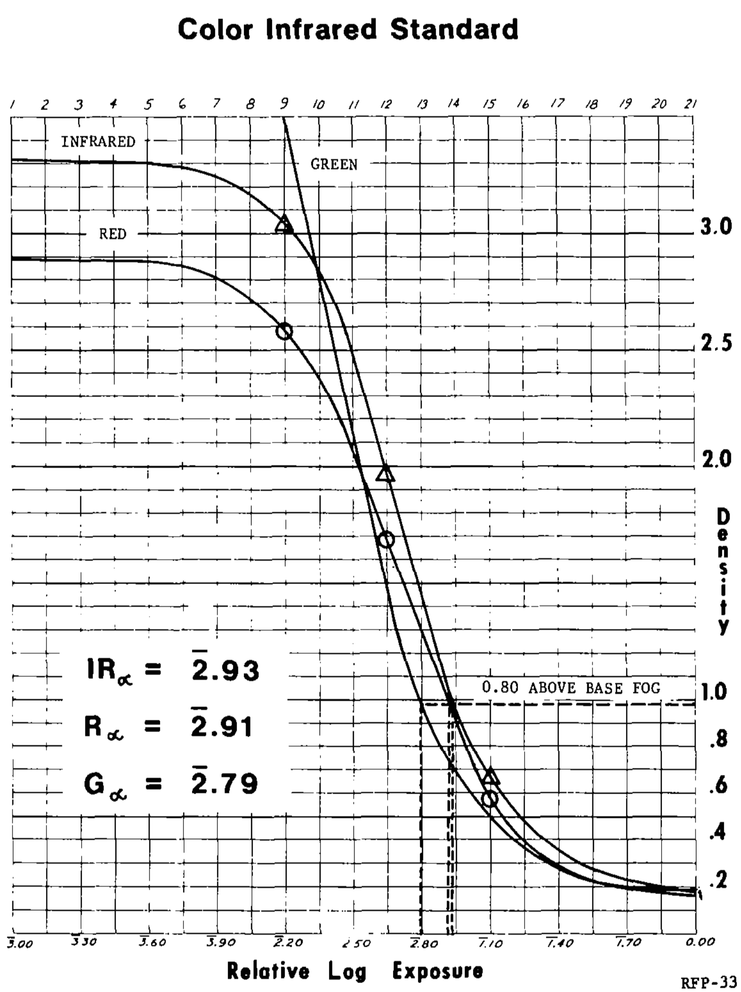
2. Locate, on the graph, the point where the characteristic curve of the infrared sensitive layer intersects this density level.

3. From this point drop a vertical line to the relative Log E scale and note the relative speed point value.

4. Following this same procedure, determine the relative speed of the infrared layer on the standard graph.

5. Subtract the test emulsion value from the value determined on the standard graph.

6. Finally, divide this difference by 0.30 and the result will be in f stops. A negative value indicates a need to increase exposure, and a positive value indicates a need to decrease exposure (see Figure 2 and Section 7 on the following pages.)



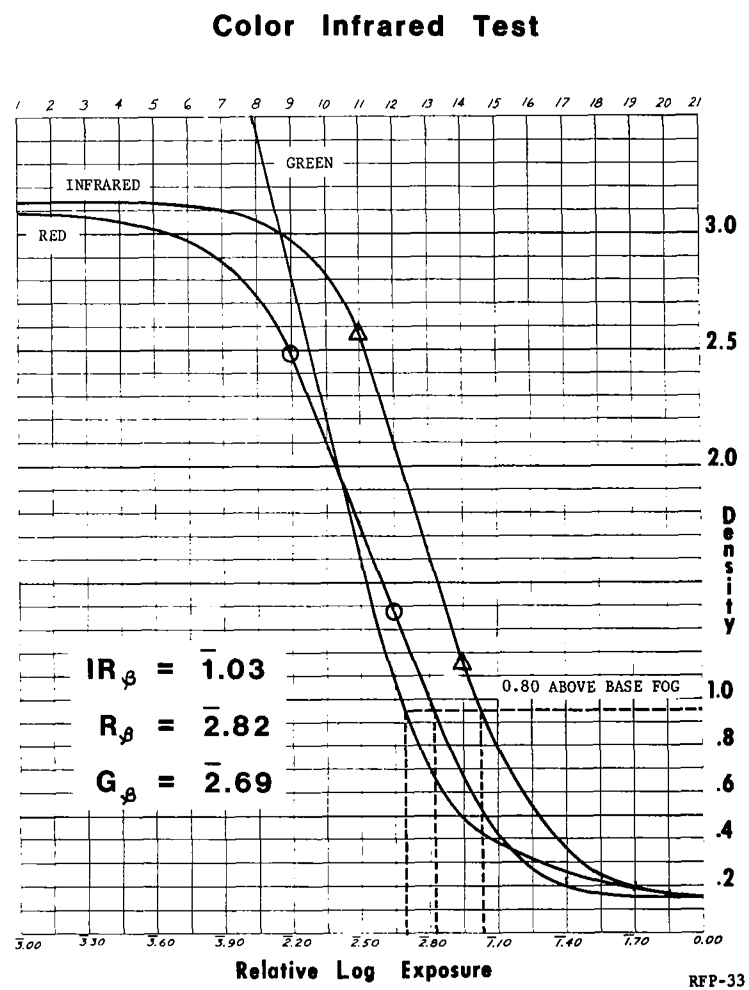


Figure 2. Comparison Procedure

6. -- Continued.

Once the exposure correction for the infrared layer is determined in Log E, the color balance for each test emulsion is checked against the standard by computing the Δ Log E (relative speed difference between the test and standard) for both the green and red sensitive layers. The speed points for these layers are computed at the same density level as the infrared layer for each emulsion. The total color balance shift is then determined by subtracting the Δ Log E of the infrared sensitive layers from the Δ Log E of the green sensitive layers and subtracting the Δ Log E of the infrared sensitive layer from the Δ Log E of the red sensitive layers. These two values are then used to determine the proper filtration to be used over the lens of the camera. The apparent speed of the green sensitive layer is reduced by magenta color compensating filters, and the apparent speed of the red sensitive layer is reduced by cyan color compensating filters. The values of the filters to be used are the same as the final Δ Log E for the red layers and the final Δ Log E for the green layers when rounded to the nearest 0.05 Log E. The reason for subtracting the infrared Δ Log E shift from the red and green components is that the correction for the infrared layer is accomplished by increasing or decreasing the exposure, which affects the remaining two layers equally.

7. EXAMPLE OF COMPARISON PROCEDURE FOR CALIBRATION USING THE VALUES FROM FIGURE 2.

To Calculate the Speed of the Test Roll Relative to the Standard:

$$\text{Relative speed differences } (\Delta\ IR) = IR_\alpha - IR_\beta$$
$$= \bar{2}.93 - \bar{1}.03$$
$$= -0.10 \log E$$

The negative value obtained indicates that the speed of the test roll is slow, relative to the standard, and an increase in exposure is required. To determine the increase in f stop, divide the absolute value of the relative speed differences by 0.30.

$$\frac{|-0.10|}{0.30} = \frac{0.10}{0.30} = 0.3 \text{ stop}$$

To Determine the Appropriate Color Compensating Filters:

$$\Delta R = R_\alpha - R_\beta = \bar{2}.91 - \bar{2}.82 = 0.09 \log E$$

$$\Delta G = G_\alpha - G_\beta = \bar{2}.79 - \bar{2}.69 = 0.10 \log E$$

Since the change in exposure equally affects all three layers, the relative speed differences must also be taken into account. This is accomplished by subtracting the relative speed difference of the IR layers from the relative speed difference of the red layers and the green layers.

7. -- Continued.

$$\Delta R - \Delta IR = 0.09 \log E - (-0.10 \log E) = 0.19 \log E$$

$$\Delta G - \Delta IR = 0.10 \log E - (-0.10 \log E) = 0.20 \log E$$

These values are then rounded to the nearest 0.05 log E and used directly to select the color compensating filters.

$$0.19 \approx 0.20 \longrightarrow \text{cc } 0.20 \text{ cyan}$$

$$0.20 \longrightarrow \text{cc } 0.20 \text{ magenta}$$

$$\text{cc } 0.20 \text{ cyan} + \text{cc } 0.20 \text{ magenta} \longrightarrow \text{cc } 0.20 \text{ blue*}$$

Rolls of film from this batch can now be exposed with cc 0.20 blue filtration and a 1/3-stop increase in exposure, and will produce imagery with the same color balance and speed as the standard.

*Equal values of cyan and magenta are equivalent to an equal amount of blue.

8. CONCLUSION.

The calibration procedure described in this paper has been used successfully by the Earth Resources Aircraft Project (ERAP), NASA Ames Research Center, since June 1973. The standard characteristic curves are those used by ERAP for most color infrared photography. Because these flights are flown at 65,000 feet, the sensitivity and response standard is biased by atmospheric attenuation. The same philosophy and procedures for determining standard color balance can be applied to lower altitude aircraft operations in order to achieve more uniform response and discrimination.

Variation in exposure and filtration was selected to shift the response characteristics because consistency is more easily achieved by this method than by variation in processing. This procedure has demonstrated the ability to produce high-altitude color infrared photography having consistently uniform color balance.

These photographs are faithful reproductions of color infrared imagery acquired simultaneously over the Golden Gate, San Francisco, California by a NASA Ames Research Center Earth Resources Aircraft Project U-2 Aircraft.

The same film emulsion batch (2443-105-1) was flown in two 24-inch (609.6 mm) focal-length cameras (HR-732). The photograph on the left was flown with the normal Wratten 12 filtration while the photograph on the right was flown with predetermined color compensating filters in addition to the Wratten 12. The procedure for standardizing the response of color infrared films is described in this paper.